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RECOMMENDATIONS CONCERNING AN INTERIM ANNUAL INDIVIDUAL OCCUPATIONAL EXPOSURE LIMIT FOR RESPIRABLE QUARTZ

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ABSTRACT

This paper presents AECB staff recommendations on the desirability of an annual individual occupational exposure limit for respirable quartz and on the magnitude of this limit, for uranium miners. Justifications are presented for the magnitude of this suggested limit for respirable quartz, drawing on experience gained in Ontario uranium and non-uranium mines and on that in other countries.

The suggestion is made that an exposure limit be set for an interim period in order that additional information on the adequacy of the magnitude of the limit may be acquired. To complement the suggested exposure limit, it is proposed that a co-existing control program of action levels, to be triggered at various respirable quartz concentrations, be set up. It is the contention of this paper that the degree of protection afforded to individuals by the suggested exposure limit would be equivalent to the time-weighted average threshold limit value derived from recommendations, based on group average exposures, of the American Conference of Governmental Industrial Hygienists.

RÉSUMÉ

Ce rapport présente les recommandations des spécialistes de la CCEA quant à la pertinence d'une limite d'exposition professionnelle annuelle pour un individu exposé au quartz respirable et sur le degré de cette limite pour les mineurs d'uranium. Le degré de la limite suggérée pour le quartz respirable est justifié en fonction de l'expérience acquise dans les mines uranifères et non uranifères de l'Ontario et de certains autres pays.

On suggère d'établir une limite d'exposition pour une période d'essai en attendant que l'on obtienne plus de renseignements à propos de la pertinence du degré de la limite. Comme complément à la limite d'exposition suggérée, on propose d'établir un programme concomitant de contrôle à partir de moyens d'intervention qu'on mettrait en marche dès que la concentration de quartz respirable atteindrait divers niveaux. Le rapport soutient que le degré de protection que la limite d'exposition suggérée assurerait aux individus serait égal à la valeur du seuil moyen par rapport au temps, dérivée des recommandations d'American Conference of Governmental Industrial Hygienists à partir de l'exposition moyenne de certains groupes.

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FOREWORD

In December, 1978, the Atomic Energy Control Board made a commitment to develop an Interim Annual Occupational Exposure Limit for Respirable Quartz for application in the uranium mining industry. The work described in this document and the approach to the setting of a limit for respirable quartz is based on the Board's experience with the regulation of radiation hazards.

The regulation of exposure to respirable quartz is not within the Board's mandate and the Board has no plans to issue or implement regulations in this area. This document is being published to provide information and to enable other organizations to make use of the work that has been done so far.

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1. INTRODUCTION

As a result of discussions among the Atomic Energy Control Board, the Federal Departments of Labour and National Health and Welfare, the Ontario Ministry of Labour and the Saskatchewan Department of Labour, on the subject of uranium miner health and safety, the AECB is presenting a staff recommendation on the desirability of an annual individual exposure limit for respirable quartz for such uranium workers. The numerical value of such a maximum permissible exposure is given, as are the justifications for that choice. The suggestion is that a maximum permissible exposure be set for an interim period in order to acquire additional information on the suitability of the magnitude of the limit. Any change in the limit, from its interim value, would require full justification. This background document is intended to provide the support for the numerical value (given in Section 3) of the annual individual occupational exposure limit for respirable quartz. To complement the establishment of an exposure limit, there should be a co-existing program of action levels at various respirable quartz concentrations to initiate investigative, reporting and controlling mechanisms.

The recommended interim exposure limit is based on the observed health effects of workers exposed over the last twenty or more years, primarily, in uranium and other mines in Ontario. The populations of workers in Ontario mines were studied extensively, in terms of the incidence of silicosis and the prevailing dust conditions, in the Report of the Royal Commission on the Health and Safety of Workers in Mines (the Ham Commission Report).[1] In the Ham Commission Report, information was lacking on individual silica exposures whereas some information on average concentrations in selected areas of uranium and non-uranium mines was presented. In that Report, ten recommendations were made pertaining to the need for a numerical limit for silica exposure and related regulations and codes of practice. In recommending this exposure limit, the AECB staff have taken into consideration the recommendations in the Ham Commission Report and have made comparison to standards in use in other countries as well. (See Appendix.)

Based on its own literature review and drawing on conversations with government, university and other experts in the field, the AECB staff recommends that the interim individual annual exposure limit for respirable

quartz be set at 12 dust level months (DLM) (see Section 3). In presenting an interim occupational exposure limit for respirable quartz and in drafting this background document, the AECB staff have given due consideration to the comments and suggestions of these experts and to the Ham Commission Report on the basic requirements for a silica standard.[2] It is the position of the AECB staff that these requirements will be met by the presently suggested interim exposure limit. It is intended, furthermore, that the degree of protection for individuals afforded by the suggested exposure limit will be equivalent to that derived from recommendations of the American Conference of Governmental Industrial Hygienists.

It is important that distinction be made between the terms respirable, non-respirable, combustible, and non-combustible dust, "total" respirable dust, and respirable silica dust. The "total" dust contains combustibles (such as diesel, oil mists, etc.) and non-combustible (mineral) components. Owing to the wide variation in the combustible fraction of "total" dust, exposure limits for silica should be based on the mineral (i.e., non-combustible) fraction of the "total" dust. Since there may be wide variations as well in the ratio of respirable to nonrespirable dust, the AECB staff have chosen to base their suggestion for exposure limits only on the amount of respirable (and non-combustible) dust and the percent of (respirable) quartz. It should be noted that the percent of quartz in airborne respirable dust may be very different from the percent of quartz in the host ore or settled dust.

In this document, reference will be made to the generic terms silica and silica dust. For purposes of the interim exposure limit, respirable quartz is the quantity of interest, while silica or silica dust is used in the more general sense. (In the past, the terms free silica, respirable quartz, silica and silica dust have been used more or less interchangeably. In this document, no distinction is made between silica and silica dust, whereas free silica is the former designation for the more modern term of respirable quartz. Silica or silica dust contain both the quartz and non-quartz components of the respirable fraction.)

Exposure to silica dust has long been recognized as an occupational hazard. The diseases resulting from these exposures are of the pneumoconiosis type of which silicosis is one example. These diseases

appear in the lung and, generally, are chronic or slowly developing.

In Canada, silicosis was observed in the early years of underground mining among metal and non-metal miners, generally where poor ventilation conditions existed or where dust suppression techniques were absent. As health authorities became aware of the relation between silicosis and the airborne hazards which may have contributed to its occurrence, those agencies with authority over mining took steps to have the mining companies introduce forced ventilation and dust suppression techniques to reduce the concentrations of airborne hazards including silica dust.

Silica is a mineral which is common in most rock (especially in the Canadian Shield) and as such is present in varying concentrations in most mines, including uranium mines, in Ontario and elsewhere, in Canada. The most common crystalline form of silica is quartz and this form appears in uranium ore in a wide range of values (from less than 10 percent to more than 60 percent). Many of these matters are discussed in Chapter 2 of the Ham Commission Report.[1] Silica appears in both crystalline and amorphous forms. For purposes of this document, quartz is of primary interest. The other major forms of silica, such as crystobalite, tridymite and amorphous silica are much less prevalent in the known uranium mining areas of Canada and so will not be dealt with here. Should evidence show that these or other forms are a significant hazard in as yet undeveloped mine sites, the appropriate exposure limit should be set for each form. The explanation and justification of these limits, when and if they are set, should be given in the appropriate background paper.

The regulation of occupational hazards requires the promulgation of occupational health standards. Normally, these standards take the form of maximum permissible exposures or concentrations. In most industrial applications where immediately-toxic substances are known to be present, limits apply to maximum short-term concentrations because even short-term excursions above the maximum permissible limits may prove harmful. The concept of a maximum permissible short-term concentration is not appropriate for slowly-developing diseases such as those resulting from exposure to hazards such as silica dust. To quote from the recommendations of the American Conference of Governmental Industrial Hygienists (ACGIH)[3]:

"The toxicologic importance of momentary peak concentrations

> depends on whether the substance is fast or slow acting. If slow acting, as for quartz, lead, or carbon monoxide, momentary peaks are of no toxicologic concern provided, of course, they are not astronomic."

Rather, it is the cumulative exposure over long periods (usually years) to such workplace hazards that may result in a respiratory disease such as silicosis. The crucial point here is that it is unlikely that silicosis will result from a single short-term exposure to those concentrations of silica dust likely to be encountered in any operating mine which is adequately ventilated. The same cannot be said of immediately-toxic substances.

In a situation where there is immediate danger to health (such as in industrial operations where known toxic substances are present) the concept of a short-term threshold limit value (or TLV) is a logical one. In this case, the special category of a Short-Term Exposure Limit has been established (TLV-STEL). Generally, the TLV-TWA (time-weighted average) is that concentration of contaminants which will not likely result in adverse effects to the individual during or following his repeated exposure for a normal 8-hour workday or 40-hour workweek. A full description of TLVs (and related concepts for specific substances) is given in the ACGIH document.[3]

2. THE BASES OF THE INTERIM INDIVIDUAL EXPOSURE LIMIT FOR RESPIRABLE QUARTZ

The purpose of this section is to explain both the physical and epidemiological bases of the recommended interim exposure limit for respirable quartz. The physical basis will be established by means of a review of the methods of measurement of respirable quartz, the types of instrumentation and their sampling characteristics. These aspects will be compared and contrasted with the more modern methods used in underground mines today. The epidemiological basis will be formed from a review of the studies of silicosis mainly among workers at the Vermont granite sheds. The group average exposure assignments in those studies will be evaluated in terms of their applicability to a system of individual exposure estimates as set out in the present document. The two bases, while complementary in concept, are closely intertwined, in fact. For purposes of this discussion,

then, the physical and epidemiological bases will be discussed together. Information on the physical and epidemiological bases of the respirable quartz exposure limit is gleaned from several sources, from historic to modern. For the historic perspective, we quote from the NIOSH document:[4]

> "It is from the Vermont granite industry that the most extensive and complete environmental and medical data are available for establishing a recommended environmental limit for exposure to free silica."

("Free silica" is to be understood to be equivalent to "respirable quartz".) The more modern information is obtained from experience gained in metal mines, chiefly in Ontario.

Estimates of the exposure of the earliest workers in the Vermont granite sheds (1924-25) were equivalent to the range of concentrations of 27 - 59 mppcf (million particles per cubic foot), where the quartz content of the dust was in the range 25 percent to 35 percent. The basic measurements of concentrations (from which the exposures were derived) were done with a Greenberg-Smith impinger. (The impinger is an instrument used for the determination of dust, based on inertial collection followed by gravitational settling in a liquid and particle counting.) At the concentrations of dust measured (namely 27 - 59 mppcf), silicosis was observed in all workers within four years. It was then concluded that a "safe" level of dust exposure in the Vermont granite sheds was in the range 9 - 20 mppcf. A re-study of the granite industry in 1937 indicated that unfavourable health effects on the group of workers were unlikely below 10 mppcf.

This figure of 10 mppcf taken with an impinger, while numerically equivalent to 353 particles per cubic centimetre (ppcc) would be read as between 500 and 1000 ppcc by a konimeter, the engineering control instrument used in Ontario mines.

However, as will be discussed later, there is no unique relationship (unless the particle size distribution is known) between particle counts and the mass of respirable silica, the latter being determined by gravimetric means. (The gravimetric sampler, used in the measurement of respirable dust, has been designed to approxiate the deposition characteristics of the pulmonary section of the human respiratory system.) Despite the lack of uniqueness, a comparison of a large number of impinger and gravimetric measurements done in the Vermont granite sheds in 1965 and 1966 revealed

that, on average, for the Vermont granite sheds, 10 mppcf corresponded, approximately, to 0.1 mg/m^3 (or 100ug/m^3)* of respirable silica, over the entire range of the percentages of quartz in the airborne silica. For purposes of epidemiology and standard setting in the United States, it was assumed that the same relationship held in the earlier years of mining activities in the Vermont granite sheds.

In 1968, the American Conference of Governmental Industrial Hygienists (ACGIH) adopted this correspondence between the count and size-selective mass methods for later incorporation into their Documentation of the Threshold Limit Values[5] in the form of a "basic value" of 0.1 mg/m^3 for respirable quartz.** (The ACGIH "basic value" of 0.1 mg/m^3 is based on the much higher average exposures of earlier groups of workers (not individuals) in U.S. mines and quarries, as previously mentioned. On the other hand, the AECB's suggested interim exposure limit (with an individual weighted average concentration-equivalent of 0.2 mg/m^3) is based to a large extent on individual exposure extimates in operating uranium mines in Canada). In 1969, Ayer, writing in the American Industrial Hygiene Association (AIHA) Journal[6] re-affirmed the correspondence of 10 mppcf and 0.1 mg/m^3. The approximate factor of two difference in the relationship between the Vermont study and the Ontario situation is explained partially by the approximate factor of two difference in quartz content of sampled aerosols in the Ontario mine. Particle size and size distribution of the silica also play a crucial role. (See Section 7.)

A note of caution must be sounded in the direct application of any occupational limit to an industry different from the one(s) used to derive the limit. The original studies, which provided the epidemiological evidence on which the TLV was based, had a set of characteristics (of the airborne aerosol) which were, likely, quite different from the aerosol

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* Footnote: In this document, ug means microgram.

** Footnote: The ACGIH TLV is normally given as a percentage formula $\frac{10}{\% \text{ respirable quartz} + 2}$ mg/m^3. This was introduced necessarily in the early days when analytical methods for small airborne dust samples were not developed. However, as the proposed reference method can measure quartz on individual samples, these can be compared directly with the "basic value".

characteristics of present-day uranium mines. To quote the NIOSH document:[4]

> "Because of variations in types, size and density of particles in other industries, it is not clear that the same limit, in terms of number of particles, will properly describe safe exposures in these other industries producing airborne free silica."

By extension, a similar qualification applies in the case of limits based on respirable mass. This point of view is shared by W.H. Walton, a noted industrial hygienist from the U.K., who also emphasized that the distribution of exposures in a given study group be matched to another group when similar exposure limits are applied[9].

When particle size and size distribution are not taken into account, a many-to-one correspondence may exist between the number distribution (in ppcc) and the mass distribution (in mg/m^3). For analogous konimetric and gravimetric measurements made simultaneously at an Ontario uranium mine, 300 ppcc (somewhat less than 10 mppcf) corresponded to a range of 0.1 mg/m^3 to 0.2 mg/m^3 of respirable quartz in two studies.[22,18] When averaged over all mining jobs, in stopes only, the correspondence was 300 ppcc to about 0.1 mg/m^3. When averaged over all mining jobs and all locations, the correspondence was 300 ppcc to about 0.2 mg/m^3. It is important to note that for one of these Ontario mines, this relationship between konimetric and gravimetric determinations was valid for average conditions, but showed wide variability at specific locations and jobs. Measurements in the Elliot Lake uranium mines using Campeds instrumentation[20] have shown that the quartz content of the "total" respirable dust was in the range of 10 percent to 60 percent. (In the absence of the superimposed "basic value" of 0.1 mg/m^3, the TLV range for the "total" respirable dust for these quartz percentages would have been 0.85 mg/m^3 to 0.15 mg/m^3.)

For application of the proposed interim exposure limit, one must, therefore, relate the average exposure of a group to the anticipated exposure of an individual within that group. This means that one must consider the frequency distribution of exposures at a specific facility such as a uranium mine. For example, in the analyses[8,23] of concentrations

of respirable quartz (based on gravimetric sampling) in two Canadian uranium mines, it was found that about 90 percent of the concentration measurements were less than a factor of two times the mean value, for the entire mine, as shown in Figures 1 and 2. It should be noted that such results were obtained in the absence of an action level program (See Section 5). (Of course, the frequency distribution will be narrower when only a single activity or a single location within the mine is considered.) Generally, such distributions of concentrations are highly skewed in such a way that the largest fraction of exposures of the workforce (engaged in a single activity or in a single location) is considerably below the equivalent exposure limit, with the tail of the distribution extending out to some point near the exposure limit. In fact, for the two sets of data shown in Figures 1 and 2, it was found that the distributions were lognormal. In a subsequent study of respirable quartz concentrations carried out in the Elliot Lake mines, it was found that most distributions of respirable quartz were lognormally distributed[23].

Examples of such distributions of concentrations for two different mines are given in Figures 3 and 4. In these examples, data on mean concentrations of respirable quartz were obtained by weighting individual concentrations by the number of measurements at those concentrations. For various occupations within each mine (References 7, 10, and 22) the mean concentrations have been combined with the number of persons working in those concentrations to provide the weighted-average concentration (MA) for the mining population in each case. The weighted-average concentration is demonstrated in each case to be below or near the commonly-accepted ACGIH TLV-TWA of 0.1 mg/m^3.

It should be pointed out that the Rio Algom Ltd. data (Fig. 4) were collected in 1977/78 while the Denison Mines Ltd. data (Fig. 3) were collected during 1980. Different mining methods and practices may also account for the differences in the observed average concentrations of respirable quartz in the two mines. No specific engineering control (action level) program based on gravimetric sampling was in place at either mine during either of the data-collecting periods. These specific distributions are illustrative, only, and one would not expect the same shape, or mean, for every operating mine. Nevertheless, the characteristic elements are displayed, as are their relation to the ACGIH TLV-TWA of 0.1 mg/m^3.

It should be stressed that konimetric data were not acquired by Denison Mines Ltd. over the same time period that the gravimetric data (shown in Figure 1) were obtained. For Rio Algom Ltd., the konimetric data (obtained over the same time period as the gravimetric data of Figure 2) are shown in Figure 5. In Figure 5, the distribution of konimetric data is lognormal. Therefore, in this case, there is a one-to-one correspondence between gravimetric and konimetric data, a situation which is not necessarily found in all cases.

3. CHOICE OF AN INTERIM MAXIMUM PERMISSIBLE EXPOSURE IN DUST LEVEL MONTHS (DLM)

Using the reasoning in Section 2, which differentiated between group average exposures and individual exposure limits derived from them, the AECB is suggesting an interim individual annual occupational exposure limit for respirable quartz of 12 dust level months (DLM) where:

a) one dust level month (DLM) is defined as the exposure resulting from the inhalation of air containing one dust level (1 DL) for one working month, where one working month equals 170 working hours, and

b) one dust level (DL) is a concentration of 0.2 milligrams (mg) or 200 micrograms (ug) of respirable quartz in one cubic metre of air (0.2 mg/m^3 or 200 ug/m^3).

It must be said at the outset that there is no overriding reason for the unit of exposure to be called the dust level month. The important factors are that (a) the amount of dust respired be expressible as an exposure, i.e., the product of concentration and time; (b) the maximum permissible exposure be expressible in terms of the unit of exposure; (c) the unit of concentration be directly measurable by an instrument designed to separate the respirable fraction of the dust. Therefore, any other unit or name with the equivalent meaning might have been used.

The AECB staff have suggested this unit of dust level month (DLM) purely by analogy with working level month (WLM). The interim annual exposure limit corresponds to an annual weighted average concentration of 0.2 mg/m^3 (200 ug/m^3). In contrast to the exposure limit, there is no specific limit on the concentration of respirable quartz in the working environment. That is not to say that such concentrations will not be

controlled. Control over the concentrations of silica should be exercised by a program of action levels, to be discussed later. (See Section 5.)

It must be emphasized again that the interim exposure limit should apply to individual workers and not to group averages. Further, the limit is one based on exposure rather than on concentration. The dust level month is roughly, though not exactly, equivalent to a time-weighted average (TWA) in the sense used in the ACGIH document. Crudely, the time-weighted average is constructed from the average concentration over a specified time period.

The annual maximum permissible exposure of 12 DLM arises from an exposure rate of 1 DLM for each month of exposure. (This does not imply a monthly maximum permissible exposure of 1 DLM.) The value of the dust level as 0.2 mg/m^3 was chosen for a number of reasons, to be discussed below.

Analysis of the exposures[10] to respirable quartz in Canadian uranium mines indicates that the average yearly exposure of miners is below the analogous concentration of 0.1 mg/m^3 and even more so when the weighted-average concentration is determined as in Figures 3 and 4. Application of the individual concentration-equivalent of 0.2 mg/m^3 should provide protection for the individual worker as well as maintain the concentration for the "average" worker at or below the corresponding ACGIH TLV "basic value" of 0.1 mg/m^3. This will be even more valid when the system of action levels is imposed. (See Section 5.)

While there is no doubt that the ACGIH TLV for respirable quartz is based on group average exposures in the Vermont granite sheds and elsewhere in U.S. mines and quarries, private communications[11,12] have revealed that the practice for regulatory organizations in the U.S. such as OSHA and MSHA is to apply the TLVs as limits for individuals. This practice is not stated specifically in the ACGIH or NIOSH documents and is clearly a conservative application of the TLV for respirable quartz in view of its basis. The AECB has not seen the justification for this extra conservatism and in view of the absence of a significant number of silicosis cases in Ontario uranium miners in the past twenty years (among those who started after 1960), the AECB sees no reason for recommending a more restrictive limit at this time. This absence of detrimental health effects is a direct

consequence of low concentrations of respirable quartz which have been experienced in Ontario uranium mines after 1960.

4. CUMULATIVE LIFETIME EXPOSURE

The aim of the interim annual exposure limit is to control the rate of potential damage to the lungs from silica exposure. At the limit, insignificant detrimental health effects may be expected in the long-term to the person so exposed. In analogy with the absence of a lifetime exposure limit to ionizing radiation, there appears to be no justifiable reason to impose a lifetime exposure limit for respirable quartz. An action level program (on short-term concentrations) is intended to ensure that the actual annual exposure is as far below the limit as is reasonably achievable (see Section 5). Moreover, regulatory enforcement of a lifetime exposure limit (in contrast to an annual limit) is not feasible when the mining population is as transitory as it is.

There is some evidence, based on exposures received by workers forty or fifty years ago, that suggests that there may be increased risk associated with silica exposures received at an early age in a person's working experience. This would manifest itself in a risk that would be proportional to the square or some other power of the time since first exposure. On the other hand, such epidemiological evidence may be an artifact that could be explained by exposures being lower in later years. There is no direct evidence that the biological risk will be anything other than linear with time, at time-weighted average concentrations likely to be encountered in presently-operating mines.

As mentioned in the Ham Commission Report, the average latent period for silicosis (detected between 1963 and 1974) among Ontario uranium miners was eighteen years.[13] (In the Ham Commission Report the latent period is defined as the elapsed time in years from first exposure to disability.) The exposures which gave rise to these cases were acquired before 1950 and were known to be very high. Since the early 1960s, exposures have been reduced significantly.[14] To the end of 1977, three confirmed cases of "radiological" silicosis ("5" rating) have appeared among uranium miners who first entered uranium mining in the period 1960-1964.(15) Of these, two are known to have had previous (non-uranium) mining experience while the

third appears to have had no previous mining experience. ("Radiological" silicosis may or may not be accompanied by pulmonary impairment.) No new cases of silicosis have been diagnosed among men who first entered uranium mining in Ontario since 1964. Generally, the latent period would increase as the rate of exposure is lessened. Moreover, at the rates of exposure encountered in present-day mines and as controlled by the action level program and by the presently suggested interim exposure limit, it is believed that there will be an insignificant number of silicosis cases for this post-1964 population in the years to come, which is to say that the latent period will likely be longer than the expected lifetime of the average worker.

5. ACTION LEVEL PROGRAM

The annual exposure limit for respirable quartz should be complemented by a program of action levels. An action level program is a concentration-related series of increasingly progressive actions at a specific work location within a facility beginning with, say, implementation of control measures and ending (if control measures prove to be ineffective) with evacuation of personnel from that specific location. The program is based on short-term concentrations of dust actually measured whether by konimetric or gravimetric means. An investigation of the dust conditions could be based on even a single measurement of a concentration above a specific action level. Verification that the excursion was above the action level would necessitate remedial action to reduce the concentration to an acceptable level.

In any of the data analyses referred to above, it is important to note that the measurements comprising the data were carried out in the absence of any corrective actions to reduce the existing concentrations since any such actions would change the distribution and so the description of the dust profile within the mine. The absence of an action level program accounts, in part, for concentrations above the TLV-equivalent to the exposure limit. However, it is very important to realize that the control of dust exposure should <u>always</u> be coupled with a program of action levels, relating to the control of the dust concentrations exactly analogous to the methods for control of radon daughter concentrations. When these action levels are exceeded, it would be the operator's responsibility to take appropriate

action within some specified time to reduce the concentrations to acceptable levels. It should be emphasized that acceptable levels and hence the first action level for respirable quartz concentrations for any facility should be set well below the concentration-equivalent of the exposure limit. This is in keeping with the general intent to keep exposures as low as reasonably achievable. In this way, the engineering control of the workplace environment complements the control of a worker's personal exposure. Even with an action level program, concentrations may, on occasion, exceed the TLV-equivalent to the exposure limit. This should not be regarded as a violation of a regulatory standard (if one were adopted) but as a trigger to initiate action to reduce the concentration so measured. As a reliable indicator of the concentration of respirable quartz, measurements should be made in the specific work locations and conditions (with a knowledge of the specific quartz content of the aerosol and other relevant parameters) before action levels can be instituted for that location.

6. OTHER FACTORS

It is widely believed that several factors may influence the amount and nature of silica respired. These carrier or vector effects are related to plateout and charge state characteristics of the aerosols (such as diesel, water, oil mists, blasting gases, trace elements, etc.) which may be present in the underground environment. While these effects may be of interest, their quantitative significance in the development of silicosis has not been established and they will not be dealt with in this document. Some discussion of these matters is given in a report by French.[16]

It should also be mentioned in the context of combined effects that "the irradiation of the lungs in uranium miners may modify and possibly enhance the fibrotic effects of silica".[17] It is possible that any such enhancing or modifying effects may have been the result of much higher exposures and exposure rates in the past to both radon daughters and silica. Once again, a fuller discussion of combined effects is beyond the scope of this document.

7. DETERMINATION OF CONCENTRATION OF RESPIRABLE QUARTZ

Total respirable dust includes the respirable silica and all of the

aerosols (diesel particulates, oil mists, water sprays, etc.) in the respirable fraction. The fraction of quartz in the total respirable dust is determined by the percent of quartz in the silica and by the concentration of the combustible aerosols, the latter of which is highly variable ranging from a few percent to greater than 90 percent of the total respirable dust. Therefore, one cannot infer a unique relationship between the total respirable dust and the percent of quartz. In view of this fact, an exposure limit for quartz should not rely on measurements of total respirable dust nor should the attribution of silicosis be based solely on the total mass of silica respired. (It is important to recall that the original measurements in the Vermont granite sheds were based on the use of the impinger instrument which counted particles of respirable dust. It was later studies which inferred a mass equivalence to impinger counts of respirable dust.)

Since the exposure limit for respirable quartz is expressible as a (mass) concentration (milligrams per cubic metre) multiplied by a time (months or hours), the measurement of (mass) concentration is determined most straightforwardly by a mass sampler, namely a size-selective sampler with gravimetric assessment. The fractionation into respirable and non-respirable segments is carried out by the very design of the device while the quartz content of the total (respirable) mass sampled is determined by x-ray diffraction or other methods, as discussed in Section 8.

While, historically, the method of particle counting (determined by an impinger or konimeter) has been the means of estimation of concentration, more recent experience has shown that the mass (more specifically, the mass of respirable quartz) is the important quantity, as discussed earlier.

In trying to relate konimetric and gravimetric sampling for the purpose of standard setting, it is useful to quote from Chmara and Knight[18] "...it is understandable that where fine particles predominate, the relationship between konimeter and gravimetric samplers is much better than in the case where the dust cloud is composed of particles in a much wider size range. Hence, there is reasonable correlation between konimeter and gravimetric samples for measurement in the intake and return airways and for drilling operations...However for material handling operations..., the correlation is very poor."

Based on several hundred measurements[18] which have been made in the Elliot Lake mines, it is possible to show that a given particle concentration (i.e., konimeter count) corresponds to a broad range of respirable mass (gravimetric) concentrations depending on the percentage of quartz, particle size, density and size-selection characteristics of the devices used for konimetric and gravimetric sampling. Even in cases where the konimeter count is acceptably low, the respirable quartz concentration may be unacceptably high. However, a new analysis of laboratory measurements, taking into account the aerodynamic median size for each distribution, shows that particle counts (measured konimetrically) can be related to the respirable mass (measured gravimetrically). This is shown in Figure 6, based on data from Reference 19. A similar relationship could obtain in an actual working environment, although data is lacking, currently. Unless one knows or measures the relevant parameters for each sample, the particle count, by itself, is not a measure of the biological hazard. Therefore, exposure standards for silicosis should not be based on particle counts but on the biologically more significant quantity of the mass of respirable quartz.

8. ENFORCEMENT

The AECB staff recommend a reference measurement method for determining the concentration of respirable quartz. The method is x-ray diffraction analysis for quartz as described in CANMET Report 78-7 "Mine Dust Sampling, Campeds" by G. Knight.[20] Other methods of analysis of quartz, such as ultraviolet and infrared should be acceptable if they can be shown to be comparable to the standard x-ray diffraction analysis technique. The mass of the sample is determined by comparison with "standard" quartz contained in sand from Ottawa, Illinois, U.S.A.

The type of gravimetric sampler used to gather the sample of dust should have sampling characteristics equivalent to or comparable to the deposition curves described by (1) the British Medical Research Council (BMRC) or (ii) the ACGIH, both of which are intended to approximate actual pulmonary deposition.[24] For most field situations, there is likely to be little difference among two measuring devices based on the two different curves. Mercer[25] in calculations, has found that "a sampler meeting the BMRC acceptance curve would have about 10% more penetration than a sampler

meeting the ACGIH curve". The use of two deposition curves should be retained for an interim period of time. Information gathered from many sources over the ensuing few years, using both deposition curves, should be used as a basis for re-evaluating this practice.

Periodic calibrations with an approved practical reference standard, among those service laboratories carrying out the analyses, should be required. Operators should be required to establish codes of practice including type of gravimetric sampler, sampling strategy, exposure assignment and record keeping. In addition to the interlaboratory calibrations referred to above, an audit program should be carried out by the regulatory authority.

The operator should be responsible for informing each employee of his personal exposure to respirable quartz. For purposes of long-term record keeping, the regulatory authority should request that operators make available the personal exposures to respirable quartz to the Radiation Protection Bureau for incorporation of these exposures into the National Dose Registry. This information will augment the information on radon daughters, gamma radiation and other factors, now being acquired by the Radiation Protection Bureau, with a view to facilitating future epidemiological studies.

9. SAMPLING STRATEGY

A. Exposure Estimation

(i) Individual

The key to the most accurate exposure estimate for an individual is, of course, a personal device worn by that individual on a full-time basis, near his breathing zone and such that the measuring apparatus most closely approximates the actual deposition in the human respiratory tract. In the absence of a program in which a personal gravimetric device is worn by each worker, one can devise a statistically-based, stratified sampling program to achieve an acceptable degree of accuracy in the personal exposure estimate.[21] In this case, a given full-shift sampler could be worn by a number of workers in a manner determined by the statistical sampling program. This requirement is then sufficient for the assignment of exposure to the co-workers. Surveys have shown that for groups working together, the

best exposure estimate for each worker within a group is the mean exposure of the group carrying out the same job. To quote from Knight et al:[10] "The difference between men doing the same job was found not to be significant and it is suggested that the dust sampling program should determine the average for each job and use this as the best estimate of the exposure for each man."

Another more restrictive point of view on sampling strategy focuses on the variation in concentration at a particular mine location and for a specific job at that location. Baseline data (on concentrations) would have to be collected by means of frequent samples (of less than full-shift duration). The mean concentration and dispersion of the distribution of measurements for a particular job and location could then be used in a statistical sampling program to determine the minimum number of samples required to be taken to constrain the exposure estimate to a stated error at a given confidence level for future routine exposure determinations.

(ii) Area Sampling

In locations or for specific jobs that have dust concentration measurements that have been shown to have a consistent relation to concentrations taken in the breathing zone of a particular worker, area sampling may provide a reliable substitute for personal sampling.

Permanent area sampling would be desirable in locations having concentrations of high variability as a function of time. In cases where there is spatial variability in a given location, more than one area monitor would be called for. In an extreme case of spatial and temporal variations where many area monitors would be required to establish the individual exposure, logic would suggest the use of personal gravimetric samplers.

B. Engineering Control

The engineering control function, which is short term in nature should be separated from the personal exposure estimation. Konimetry, or particle counting, has an essential part to play in assuring that the concentrations of silica are maintained at, or reduced to, acceptable levels. It is recommended that konimetry continue to be used as an engineering control device, i.e., for implementation of the action level program. The action level program should be determined on a case-by-case

basis for each facility, again in analogy with the radon daughter action level program. In addition, this program of action levels should take into account the relation between particle counts and the concentration of respirable quartz for the particular area and job in question. The frequency of konimeter measurements in a given work location may be different from that for any sampling program used to determine personal exposure.

It is important to remember that the results of personal exposure estimations can, in fact, be used as a measure of the long-term effectiveness of engineering control programs.

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APPENDIX

11. EXPOSURE LIMITS FOR RESPIRABLE QUARTZ IN COUNTRIES OTHER THAN CANADA

The following is a summary of limits for exposure to respirable quartz as employed by countries other than Canada. Also included are summaries of present average exposure levels and estimates of the risks of developing pre-silicotic symptoms after lifetime exposure at the limit.

GERMANY

Exposed Population:	Iron, Hardrock and Coal Miners
Exposure Limit[a]:	Respirable Quartz: 0.15 mg/m^3 Total Respirable Dust: 4 mg/m^3
Exposure Experience:	Exposure Period: Average Total Respirable Dust 1950s: 15-18 mg/m^3 Present: 6 mg/m^3
Risk Estimates:	Miners exposed to 0.15 mg/m^3 of respirable quartz for 7000 shifts have 5% chance of developing pre-silicotic symptoms

[a] British Medical Research Council lung deposition curve

SOUTH AFRICA

Exposed Population:	Gold Miners	Others
Exposure Limit:	200 ppcc[b]	500 ppcc[c]
Exposure Experience:	Gold Miners 1926: 240-380 ppcc 1980: 150 ppcc	
Risk Estimates:	A few cases of miners with pre-silicotic symptoms may occur in groups of gold miners exposed to 200 ppcc of dust for 20 years.	

[b] particles per cubic centimeter of mineral dust with an average quartz content of 30%.

[c] particles per cubic centimeter of mineral dust with an average quartz content of $<$ 30%.

SWITZERLAND

Exposed Population:	Hard Rock Miners
Exposure Limit[d]:	Respirable Quartz: 0.15 mg/m

[d] British Medical Research Council lung deposition curve

UNITED STATES OF AMERICA

Exposed Population:	Hard Rock Miners
Exposure Limit[e]:	Respirable Quartz: 0.1 mg/m^3

[e] American Conference of Governmental Industrial Hygienists lung deposition curve.

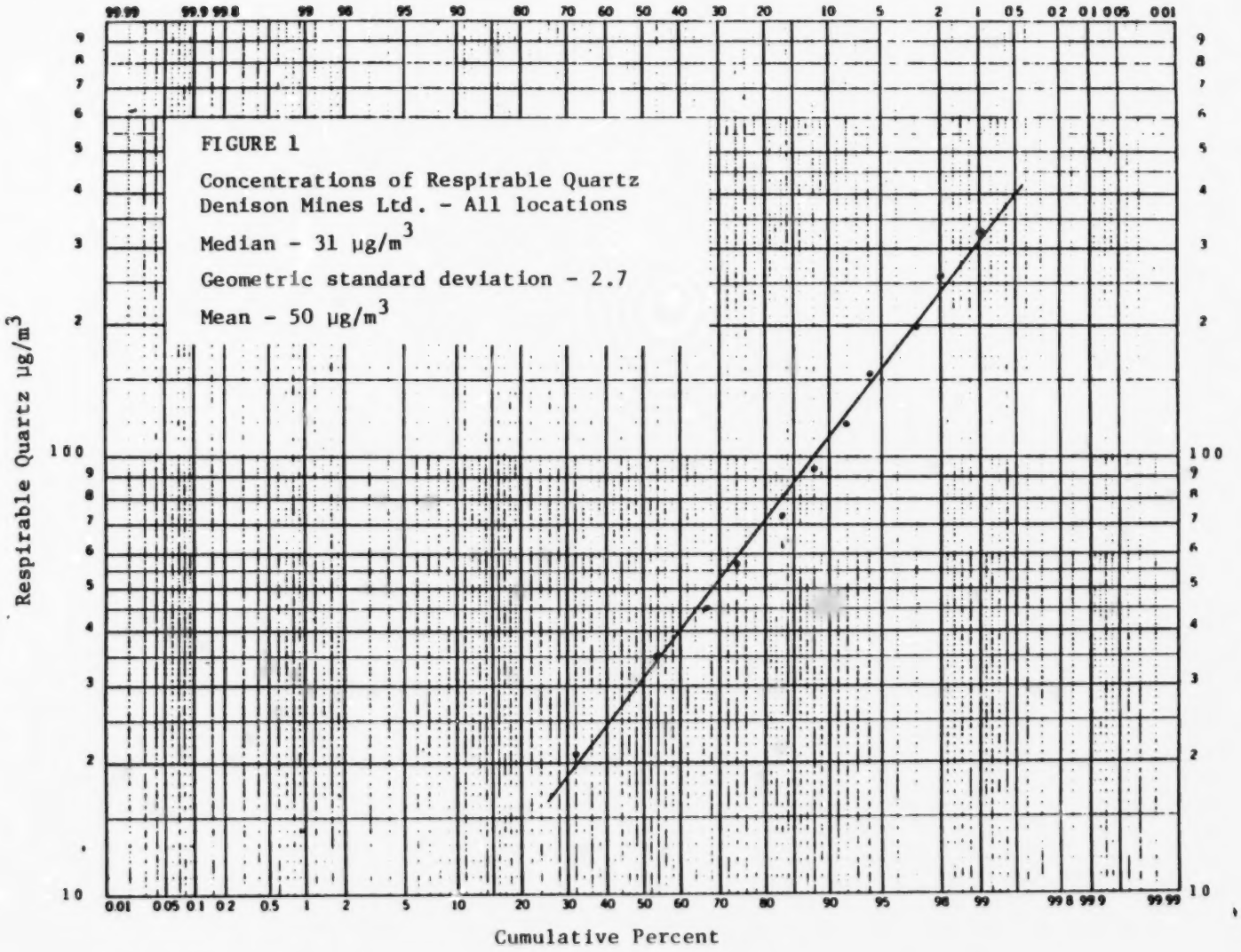


FIGURE 1
Concentrations of Respirable Quartz
Denison Mines Ltd. - All locations
Median - 31 µg/m3
Geometric standard deviation - 2.7
Mean - 50 µg/m3
Respirable Quartz µg/m3
Cumulative Percent

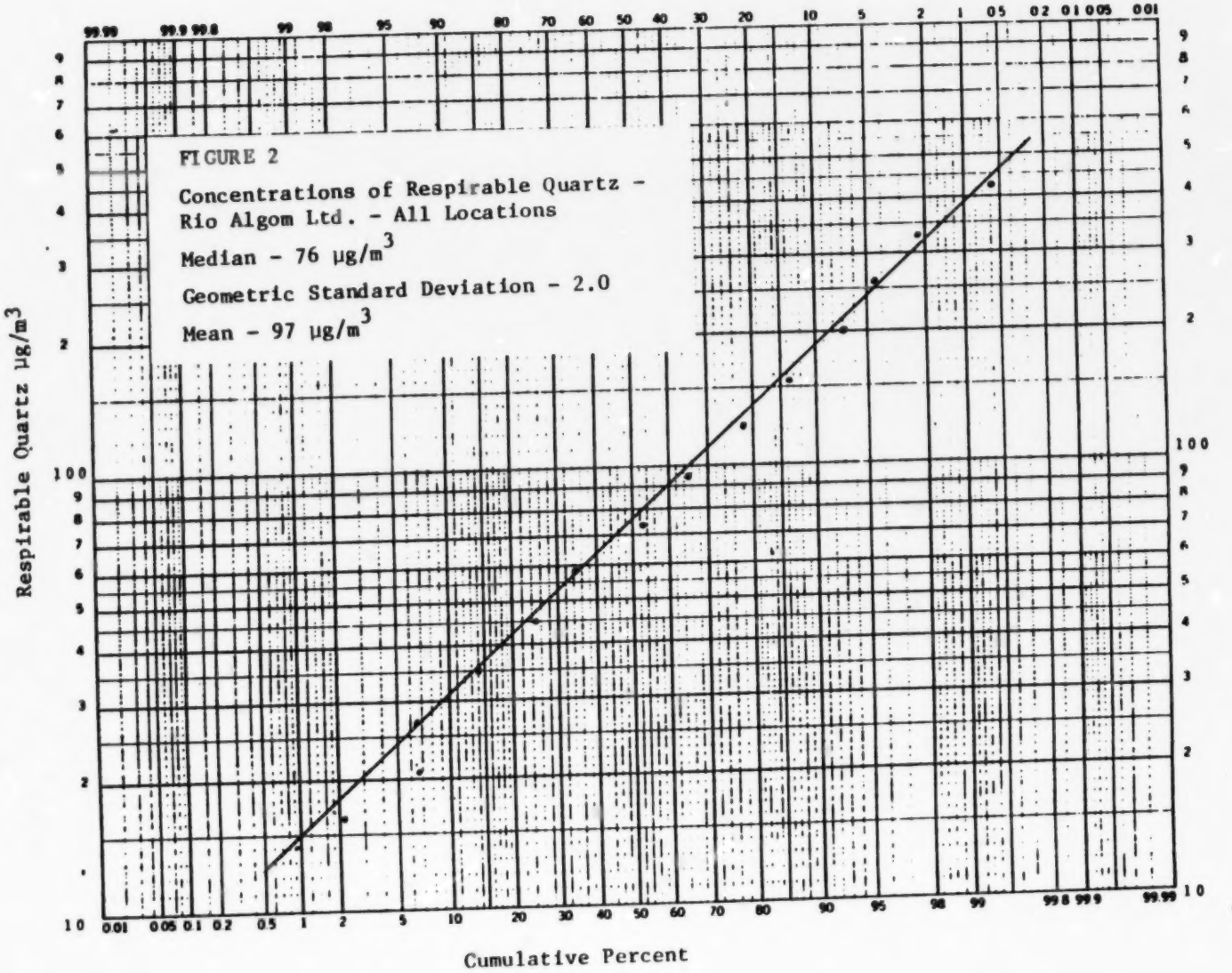


FIGURE 2
Concentrations of Respirable Quartz - Rio Algom Ltd. - All Locations
Median - 76 µg/m3
Geometric Standard Deviation - 2.0
Mean - 97 µg/m3
Respirable Quartz µg/m3
Cumulative Percent

FIGURE 3

MEAN RESPIRABLE QUARTZ CONCENTRATIONS

BY OCCUPATIONAL GROUPS

FOR DENISON MINES LTD. (1980)

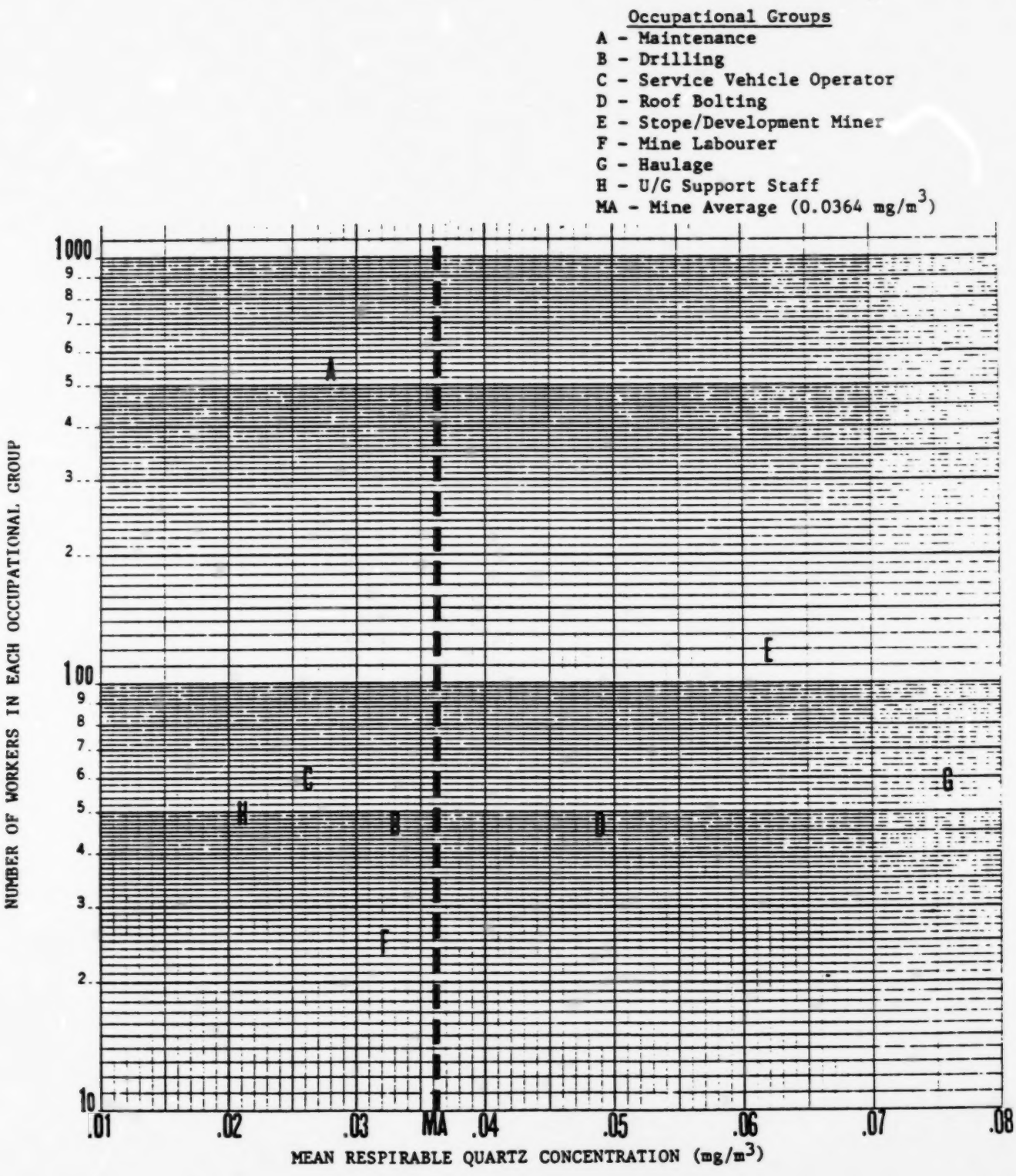
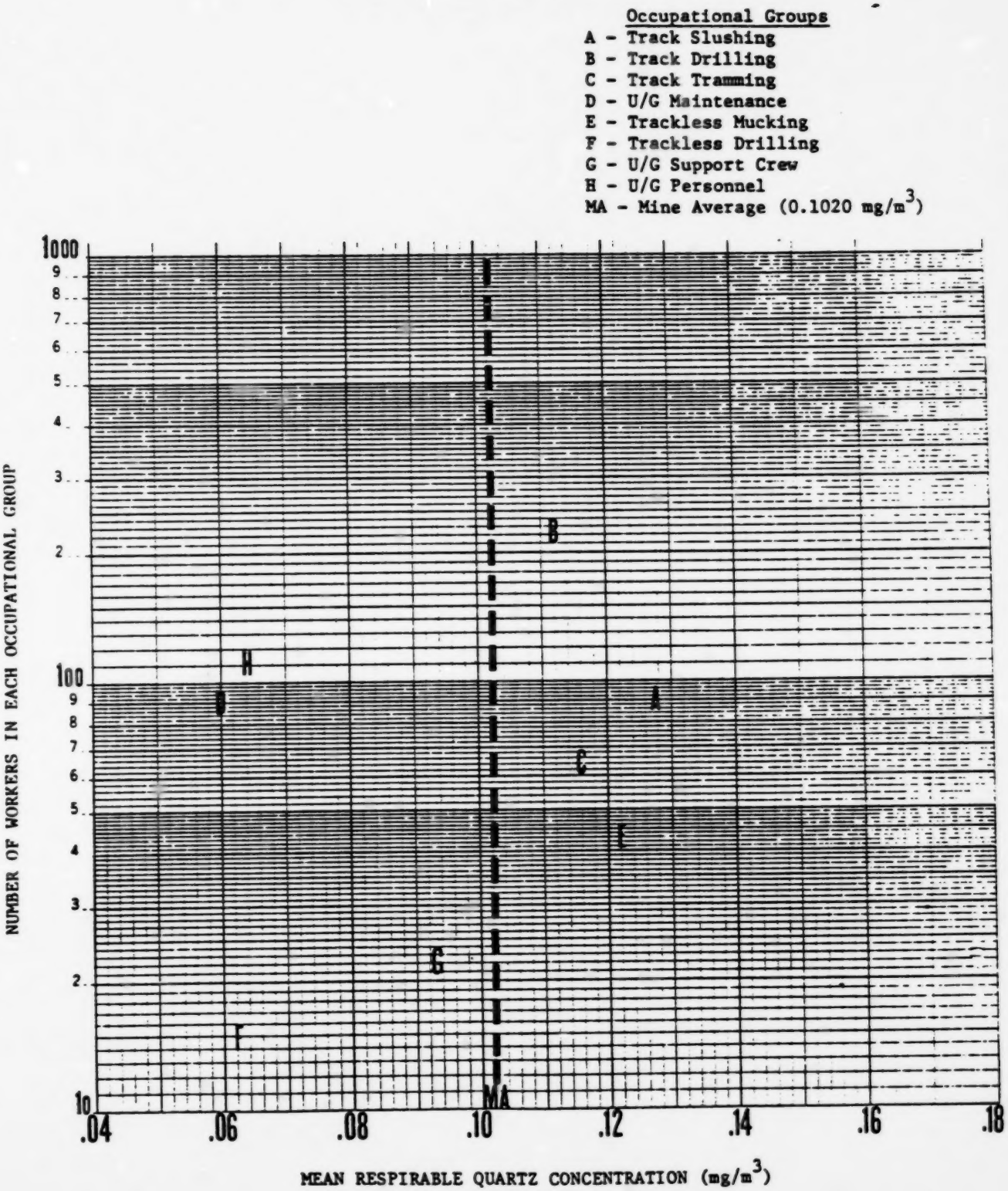


FIGURE 4

MEAN RESPIRABLE QUARTZ CONCENTRATIONS

BY OCCUPATIONAL GROUPS

FOR RIO ALGOM LTD. (1977/1978)



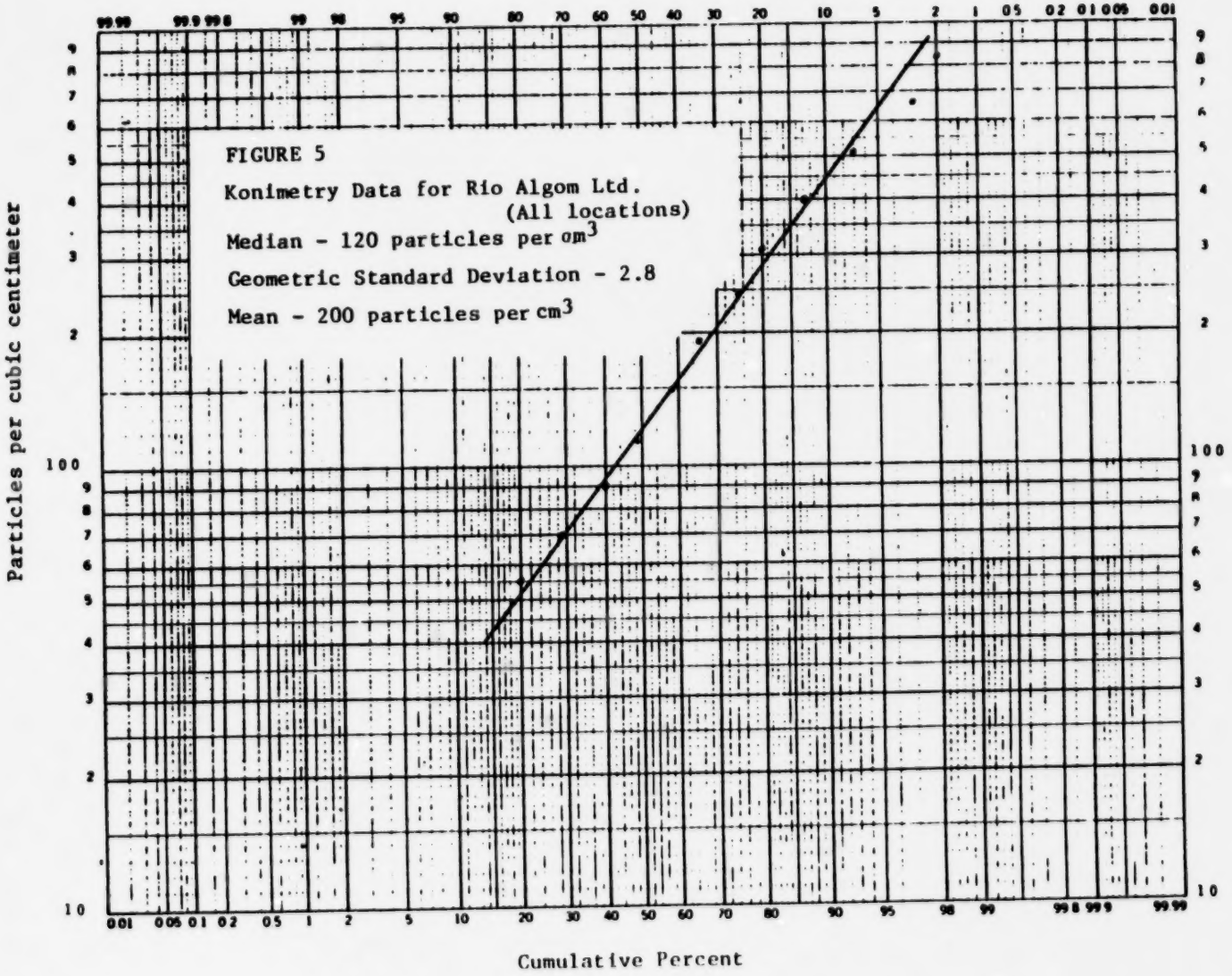


FIGURE 5
Konimetry Data for Rio Algom Ltd.
(All locations)
Median - 120 particles per cm3
Geometric Standard Deviation - 2.8
Mean - 200 particles per cm3
Particles per cubic centimeter
Cumulative Percent

POOR

QUALITY

ORIGINAL